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PUTTING LIVES ON THE LINE: THE FAST ROPE GLOVE CHALLENGE

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To protect their hands from rope friction burns during Fast Rope insertions, US troops must wear bulky leather outer gloves on top of their tactical gloves. This makes it difficult for them to operate their weapons and other pieces of kit once on the ground. This evaluation examines some possible candidate materials that may be used to make one pair of gloves for both the fast rope descent and for shooting/manipulating pieces of the kit. It also discusses considerations for glove construction and the possibility of using other non-glove solutions to tackle this issue.

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Fast Rope, Gloves, Special Forces, Burn, Friction, Abrasion, Dexterity

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1.0 Introduction

A Faster Insertion Technique

As the leading edge of the US military, Special Operations Forces (SOF) are often tasked with missions that require them to enter a hostile area quickly. Helicopters and tilt-rotor aircraft provide a speedy way to get troops where they are needed, but are not always able to land in an urban environment, or in heavily wooded areas. Therefore, these troops require a way to descend the last 40-70ft onto their landing zone. Rappelling (abseiling) out of the aircraft can take too long if the team consists of many members, all of who need to clip-in to the rappel line in the aircraft's cabin and must disengage from the line once on the ground. Particularly, if the team and the aircraft are taking fire, this insertion method can prove to be too cumbersome to be effective. The Fast Rope Insertion/Extraction System (FRIES), on the other hand, allows multiple operators to slide down a thick, 3in rope that acts as a sort of flexible firefighter's pole. By squeezing the rope with his (at present, SOF ground forces are exclusively male) hands and feet, an operator is able to control his descent and even stop on the rope, if necessary, to avoid bumping into a comrade or other obstruction (see Fig. 1).

Figure 1.: US Navy SEALs Fast Roping from a Helicopter (Hsu, 2011)

Rope Burn

Depending on the length of the descent and the amount of kit the operator is wearing, the friction between his hands and the rope can generate enough heat to cause painful burns and blisters. If he is still several feet above the ground, the operator must choose whether to continue burning his hands or letting go of the rope and falling the rest of the way down. To protect themselves from rope burn, Special Forces operators wear welder's gloves over their standard-issue tactical gloves. This solution is not ideal since after making it down, an operator must remove the welder's gloves before he can reach the trigger of his weapon, making him and his team vulnerable to enemy fire during that critical insertion period. This need for good dexterity during fast roping has already been established in the literature on military medicine. According to Thomas, Schrot, Butler & Curley, three skills cited by operators most frequently for performing a successful Fast Rope insertion include: grip strength, vigilance, and manual dexterity (p.27).[1]

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Finding Potential Solutions

In Oct 2010, the 711th HPW in collaboration with the Wright Brothers Institute issued an open innovation Award Challenge to find solutions to this Fast Rope challenge. [2] 182 submissions were evaluated from this 60 day challenge contest. These potential solutions were of two different types, material and mechanical solutions. The mechanical solutions had to clamp on to the rope quickly to be acceptable to the operators. They were also concerned about what to do with the item when the Fast Roping was completed. It was suggested in the challenge solutions that the device solutions could be made to stay with the rope once the operator descended solving this problem. The best of these mechanical solutions was a plastic-based, hinged pipe that would clamp down on the rope and allow the operator to brake by squeezing the device. Friction pads on the inside of the pipe would slow the operator down and a thick layer of plastic would insulate his hands. A 3-D printout of this solution (see Fig. 2) was made with the intention of testing it along with the gloves; however, the Pararescue instructors did not feel comfortable having the participants try this solution until it was more heavily ruggedized. Therefore the testing of this solution is not part of this report.

Figure 2. Fast Rope Descent Device

Although a heftier version of this device could allow an operator to make a descent while using his tactical gloves (getting around the two-glove problem), there are some advantages that a glove-based material solution could offer that would be difficult for a device to match, including: the ability to feel the rope (which gives the operator an intuitive sense of how hard he needs to brake); the ability to use the same solution for rappelling and Fast Roping; and the ability to use the same solution for handling hot objects during a rescue/recovery mission (such as aircraft/vehicle debris). The most promising of the glove material solutions had low thermal conductivity. They were 1) Silica Aerogel, 2) Silica/Ceramic NASA Q-Fiber and 3) Nomex/Kevlar. Silica Aerogel has the lowest thermal conductivity of any known solid and was recently made into a viable material by the company Aspen Aerogel.[3] The other materials have lower conductivity than the current leather gloves.

Therefore the hypothesis of this effort was that better-insulating materials (those with low thermal conductivity) would better protect the operators from burns and could be made into a lighter form factor than the current gloves, so the aim of our evaluation is to determine if these ideas:

- Will be able to insulate the operators' hands from heat;
- Will allow the operators access to their weapon immediately after dismounting the rope;
- Will be comfortable and could be used in situations other than Fast Roping (e.g. picking up hot objects)

Building a Better Glove

The first iteration of this study established which materials might be most useful to incorporate into a pair of fast roping gloves. We evaluated some of the materials proposed in challenge, pitting them against commercially available Fast Rope gloves, and other commercially available heat-resistant gloves used in metal forging.

The two materials from the Fast Rope challenge that held the most promise for further development included a Kevlar/carbon fiber blend and a silica aerogel pad that could be incorporated into the palms and finger pads of the glove. For this evaluation, we tested:

- The Superior Glove Works Cool Grip, which is made from a 50/50 blend of Kevlar and carbon fiber. The carbon fiber helps to reflect heat and the Kevlar provides good heat and cut resistance;[4]
- A prototype glove by Mechanix Wear, which had a silica aerogel pad sewed into the palm (the aerogel was only placed in the palm and there was no insulation for the fingers).

Additionally, we tested some commercially available metalworking gloves, which are rated for heat or abrasion resistance. These included:

- The Superior Glove Works Kevlar gloves with SilaChlor Lining and Temperblock (silicone-coated Kevlar) palms, which are rated to withstand temperatures up to 600°F;[5]
- The Superior Glove Works Emerald CX Wire-Core Gloves which have a stainless steel wire core which makes them cut resistant and are coated with a nitrile palm that may provide some thermal protection;[6]
- The HexArmor GGT5, which are lined with Thinsulate and have palms, that are covered with a thin layer of SuperFabric for abrasion resistance.[7]

Finally, we compared these candidate materials with those that are already being used in commercially available Fast Rope gloves:

- The current-issue Fast Rope outer glove is the Ansell Hawkeye Heavy Duty Cattlehide Work Glove (since it must be worn with an inner tactical glove, it will be tested with the inner glove);[8]
- The Yates Tactical Rappel/Fast Rope Glove is slightly less bulky than the current-issue glove, but is still made out of thick full-grain leather (it is also intended to be used with an inner glove).[9]
- The Oakley Fire Resistant Fast Rope Glove is designed to be a Fast Rope glove that has a tactical glove form factor and is constructed out of Nomex with an aluminized Carbon-X palm covered with Keratan to help insulate the hand and provide abrasion resistance (US Standard Issue).[10]

2.0 Methods

Equipment and facilities

For all tests, the primary requirement for the temperature data acquisition system was for the equipment to be small and light enough to be carried by the test operator during the test without requiring a cable to a stationary recorder. This requirement limited the choice of equipment to either a portable data recorder or a telemetry system broadcasting to a stationary receiver. Due to time and cost restraints, the system chosen was a data recorder based on the Arduino, an open-source electronics prototyping platform.

This system consists of an Arduino Uno motherboard with a data logger daughterboard. The microprocessor used in the motherboard is a low-power Amtel ATmega 328, which has six analog input pins and 13 digital I/O pins. The analog input pins are multiplexed to an internal 10-bit resolution successive-approximation A/D converter. To better match the expected signal levels, the reference voltage for the analog-to-digital converter was changed from the default 5V reference to the internal 1.1V reference voltage. Four of the digital I/O pins were wired to 'Start' and 'Stop' push-buttons and an indicator LED to form a simple operator interface.

The data logger daughterboard contains a connector for a Secure Digital (SD) memory card. The card chosen for this project was the 2GB size, which is inexpensive, easily available and large enough to store the results of thousands of tests. The data is written to card as a text file that can be read by a laptop computer after the tests. The assembled system is capable of recording six channels of data at 40 samples per second to the SD card. The Arduino Uno, the Data Logger daughterboard, a standard 9Vbattery, recessed 'Start' and 'Stop' pushbuttons and an indicator LED were all installed in a sturdy plastic box, approximately 2.25" x 3" x 6.25".

For the operational tests, each test glove (right hand only) was instrumented with six K-Type thermocouples placed in different positions on the hand based on our subject matter expert's (a Pararescue master instructor) experience of where hotspots occur in the current issue gloves. Because thermocouples are low voltage non-linear sensors, some kind on amplification and linearization circuitry was necessary to enable the analog-to-digital converter in the Arduino to properly read them. We chose a Model SMCJ-K Thermocouple-to-Analog connector/converters from Omega Engineering, Inc to use as an amplifier. These are battery-operated amplifiers that produce a linear analog signal at 1mV/^{o}F. Each amplifier is approximately 1" x 2" x 4" and weighs 2.5oz. The six Thermocouple wires run from the glove, along the test operator's arm, to the data logger and amplifiers, which were placed in a medium-sized belt pack located on the test operator's front waist below the body armor. The complete system weighs approximately 2lbs and did not interfere significantly with the operator's movements.

The combination of the Arduino data logger and the Omega amplifiers produce readings with a resolution of 2^{o}F and an accuracy of +/- 4^{o}F. Since the purpose of the tests was to determine the relative effectiveness of the various glove materials, this level of accuracy was considered sufficient (see Fig. 3 for data logger setup).

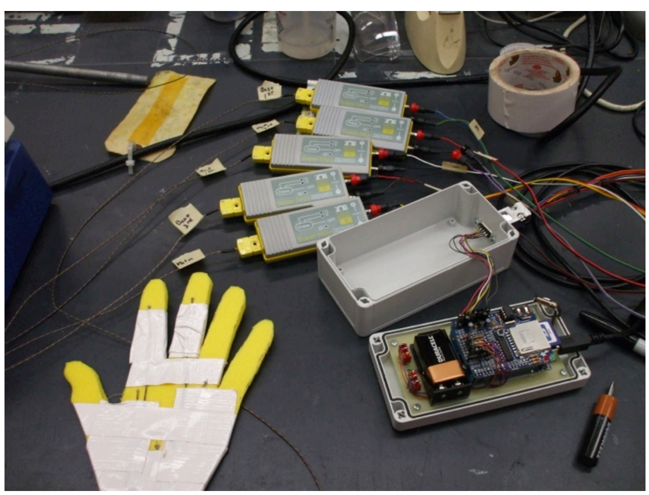


Figure 3. Data Logger Setup

To gauge the heat resistant properties of each glove in a controlled setting, they were first evaluated in the laboratory. This initial experiment took place at the materials directorate of the Air Force Research Lab, using a hotplate and the temperature measuring equipment described above.

For the operational test, we attempted to replicate as closely as possible the conditions under which operators would use these gloves. The test took place at the 342 TRS, the Pararescue Schoolhouse at Kirtland AFB, NM. On their 40ft-training tower, experimenters hung two sections of Fast Rope, one at a 20ft and another at 40ft. The gloves were outfitted with thermocouples to sense how hot the inside of the prototypes became during the descent. These thermocouples were small enough that they did not affect the operators' grip on the rope. This information was then fed to the same data logger that was used in the hotplate test, which was worn by the operator. For those gloves that used an accompanying inner glove, only the inner glove was outfitted with sensors.

Procedure

All of the glove designs were first tested on a hotplate without any hands inside. The plate was set to 200^{o}F ($\pm 5^{o}$) and the gloves were placed on top of it, palm down with 1.275kg of weight placed on the fingers and 1.5kg on the palm. Five thermocouples were attached to a two-dimensional foam hand that was placed within each glove (the arrangement of these thermocouples was similar but not exactly the same as the field test). The sixth thermocouple was used to gauge the temperature of the hotplate. The data logger then recorded how quickly the gloves heated up over the course of 5 minutes (see Fig. 4). Researchers repeated this procedure with each glove and averaged the results of both trials.

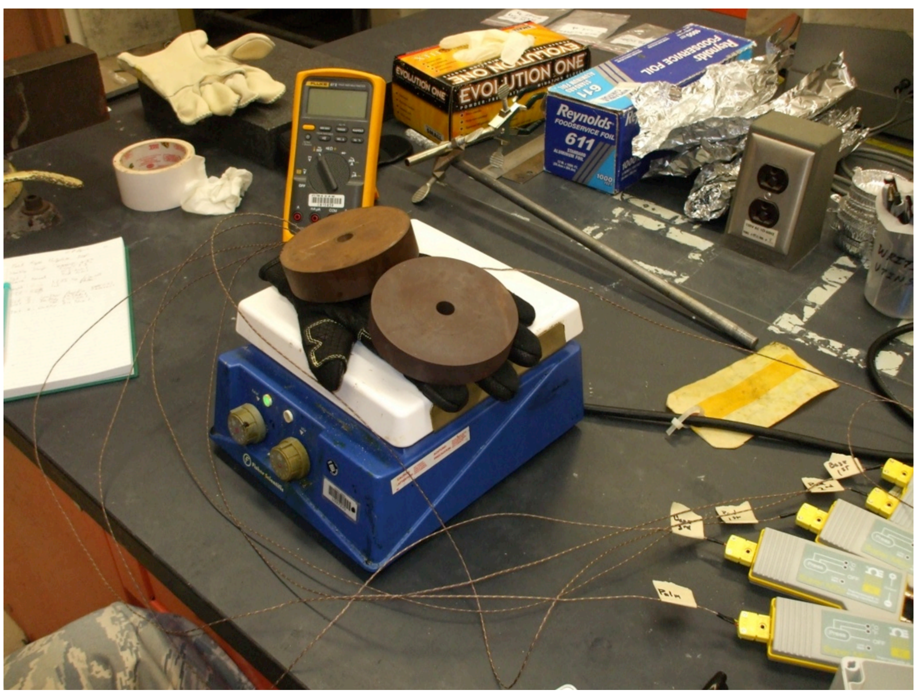


Figure 4. Hotplate Test Setup

On the day of the field test, a pararescue instructor performed safety checks on the Fast Rope test setup. Our participants were two student pararescuemen recruited from the 342TRS. Operator 1 was right-handed and weighed 180lbs. Operator 2 was left-handed and weighed 190lbs. All operators were qualified and current in Fast Roping and all initial safety checks of the gloves were performed by a pararescue instructor. A participant would begin testing each glove on the 20ft rope wearing only his body armor (20lbs). Then, he would test the same pair of gloves at 40ft and again at 40ft while wearing his full kit (20lbs of body armor + 40lb ruck sack), for a total of three trials per set of gloves (see Fig. 5). The operator would descend at approximately 10ft/sec. If on a particular trial, either he or the instructor did not believe that a pair of gloves would be able to handle testing from greater heights or more weight, then that pair was excluded from further testing. Once one operator determined the acceptable test limits for each prototype, the other operator would test each set in the same manner. For all trials, the temperature inside the gloves was recorded and at the end of each 3 trial series, operators completed a post-test questionnaire to capture their subjective impressions of the gloves.

a. b. c.

Figure 5. a: Inner Glove Outfitted with Thermocouples Attached (Gloves Turned Inside-Out); b: An Operator Donning His Full Kit and the Glove Instrumentation; c: An Operator Descending the 40ft Rope as an Instructor Watches

3.0 Results

It is important to note that for these results, the starting and ending temperatures are not important. The starting temperature can be affected by the environment (e.g. whether the test was conducted in the morning or the afternoon) and can be affected by how well the gloves had cooled down from the previous trial. The final temperature, given enough time, will always be the temperature of the hotplate or the theoretical max heat produced by the friction between the gloves and the rope. Therefore, to judge how well each glove insulates the hand, what we are concerned with is not absolute temperature, but rather rate of temperature increase over time ($\Delta^{o}F/\Delta sec$). This equates to the slope coefficient of the linear trend line (e.g. for a trend line with an equation of $y = 2x + 100$, the number "2" is the slope coefficient and represents an increase of $2^{o}F/sec$). All linear trend lines were generated with Excel.

Hotplate Test

To get an idea of how well each glove might perform once on the rope, we first evaluated how quickly the palm side of these gloves would heat up on a hotplate. For purposes of comparison, we placed a gloveless foam hand on the hotplate to see what the thermocouples would record for a "Bare Hand" ($9^{o}F/sec$). During this test, the Superior Kevlar/Silachlor/Temperblock metalworking glove seemed to provide the best protection ($.09^{o}F/sec$), followed by the Ansell two-glove solution that operators are currently using ($.18^{o}F/sec$) (see Fig. 6). These results are based on an average of all the readings taken by each thermocouple position. Since the Mechanix solution only had an insulating layer of silica aerogel sewn into the palm, it was possible that this material was providing adequate insulation for the palm, but when averaged with the unprotected fingers, this effect was being overlooked. Therefore, we also checked to see how well each glove solution protected just the thermocouple placed in the center of the palm. These results were similar to the first, with the Superior Kevlar/SilaChlor/Temperblock solution (.12°F/sec) taking the lead again. As expected, the Mechanix glove (.35°F/sec) performed much better when looking just at the palm thermocouple, overtaking the Yates Tactical Rappel/Fast Rope two-glove solution (.40°F/sec) and the HexArmor GGT5 (.41°F/sec) (see Fig. 7).

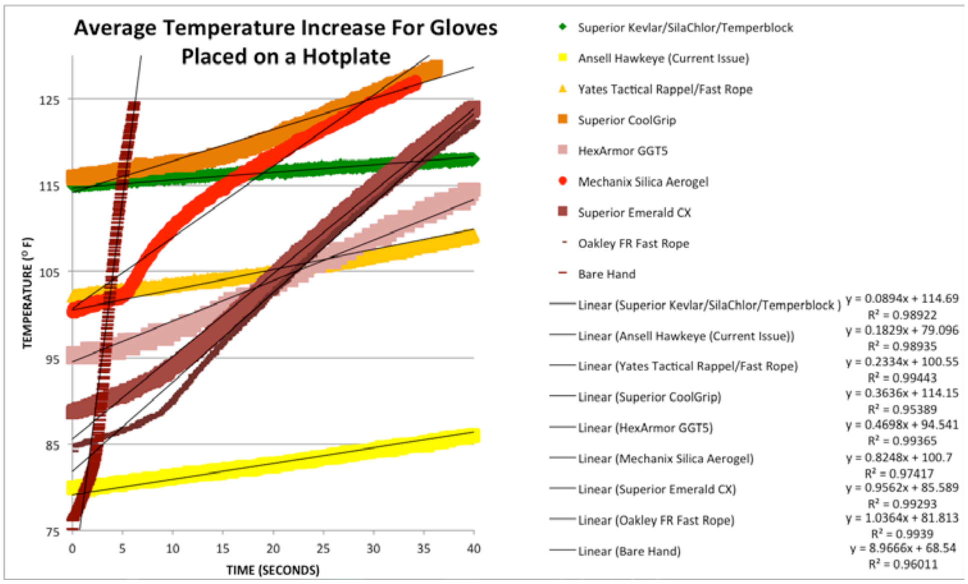


Figure 6. Results of the Hotplate Test (Averaged Across Trials and Thermocouple Positions)

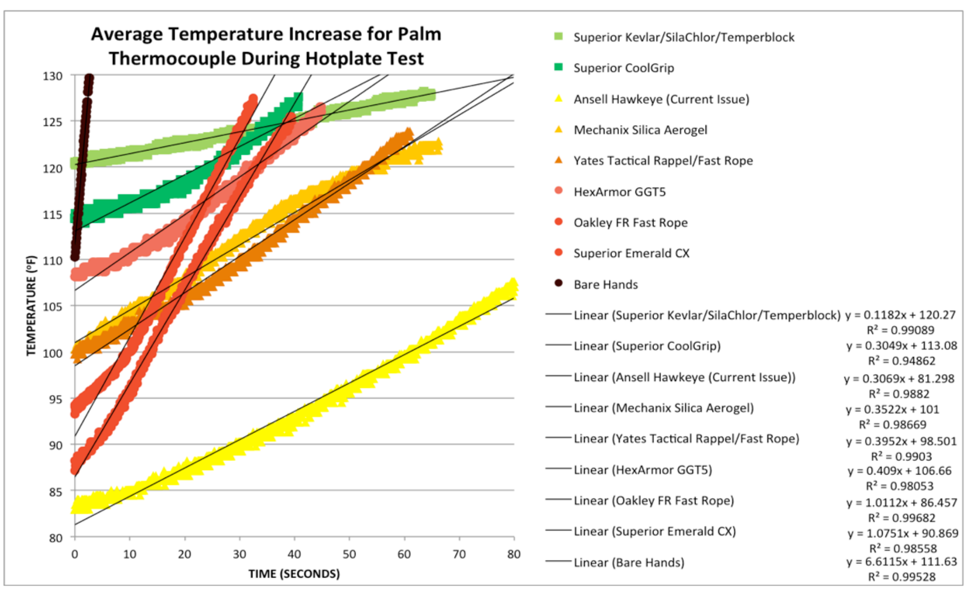


Figure 7. : Results of The Hotplate Test (Averaged Across Trials; Palm Thermocouple Only)

Overall Results During 40ft Fast Rope (Full Kit)

Six of the eight solutions were tested at 40ft, with the operator wearing his 40lb rucksack. The participants had some reservations about wearing the Mechanix gloves for the full test, because they did not adequately protect the operator's fingers from the heat. Likewise, the operator who tested the Superior Cool Grip gloves was concerned that his grip might be negatively affected by the way the material bunched up underneath his hands on the 40ft no-kit test, so they were not tested with full kit. These test results suggest that the two-glove solutions are the most effective at insulating the hand with the Yates Tactical Rappel Glove (.41°F/sec) narrowly overtaking the current-issue (.46°F/sec). Surprisingly, the Oakley FR Fast Rope Glove provided the least thermal protection (1.62°F/sec) (see Fig. 8).

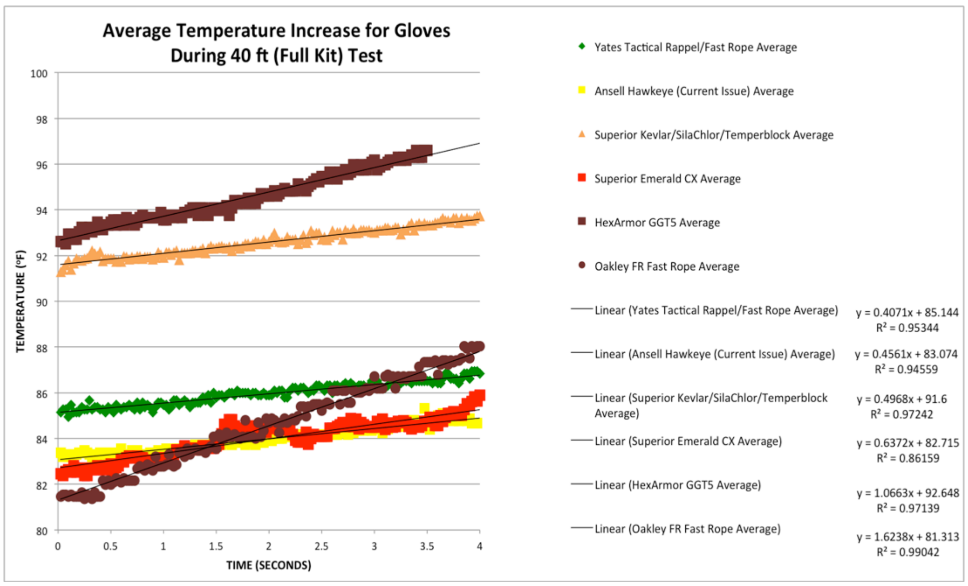


Figure 8. Results for the 40ft, Full-Kit Test (Averaged Across Participants and Thermocouple Positions)

Overall Results During 40ft Fast Rope (No Kit)

The results of the 40ft, no-kit test were useful because the operators felt comfortable testing all of the glove materials at this height with no extra gear. Operator 2 even volunteered to descend the rope with a glove that had thermocouples placed on the exterior of the palm in contact with the rope, so we could get an idea of what a bare hand would experience during a 40ft Fast Rope descent (see Fig. 9).

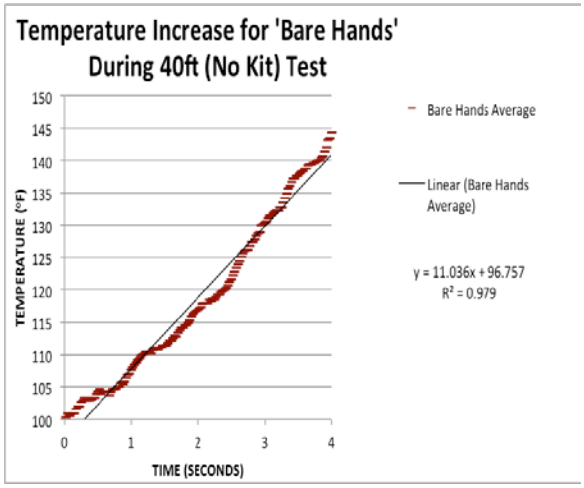


Figure 9. Results for the 40ft (No Kit) "Bare Hands" Test (Averaged Across Thermocouple Positions)

For these tests, the Superior Cool Grip performed quite well (.07°F/sec). The two-glove solutions followed close behind with the current issued solution and the Yates Tactical Rappel/Fast Rope solutions keeping the temperature increase at .11°F/sec and .21°F/sec, respectively (see Fig. 10).

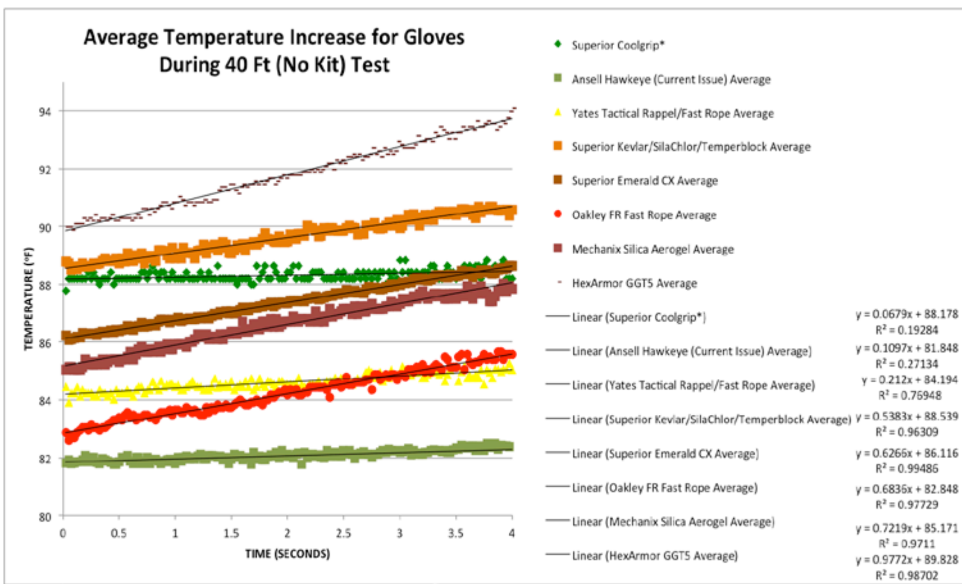


Figure 10. Results for the 40ft, No-Kit Test (Averaged Across Participants and Thermocouple Positions)

*Results Are Only Available for One Operator

However, just as with the hotplate tests, if one examines only what the palm thermocouple recorded, the effectiveness of the Mechanix silica aerogel solution (.05°F/sec) becomes more apparent. Having this protection kept its palm cooler than those of the two-glove solutions (.20°F/sec for both the current issue and the Yates Tactical Rappel/Fast Rope gloves).

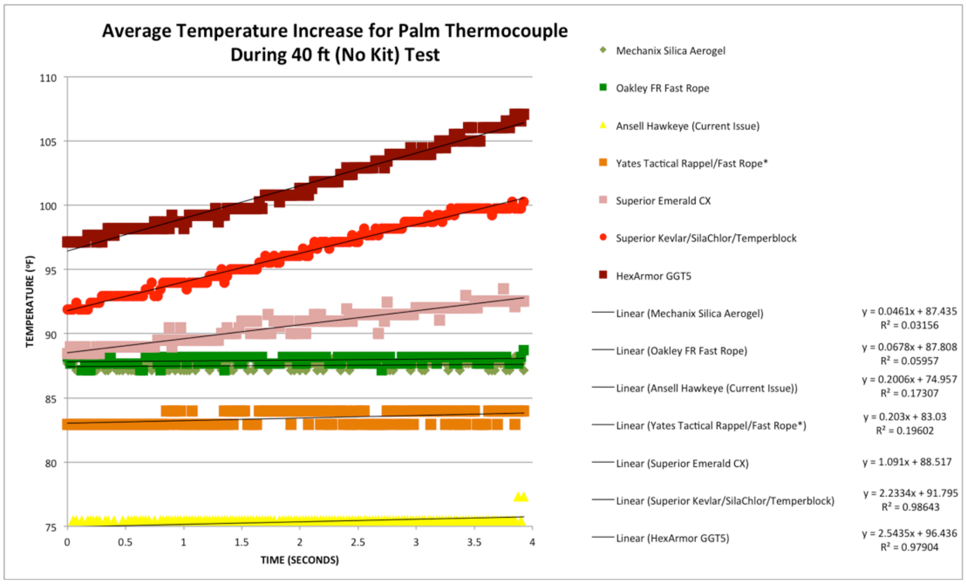


Figure 11. Results for the 40ft, No-Kit Test (Averaged Across Participant; Palm Thermocouple Only)

*Results Are Only Available for One Operator

Subjective Impressions

Along with the objective measurements of how hot particular points on the hand would become as the operator descended the rope, researchers also gave the operators a feedback questionnaire to gauge their subjective opinions of each solution (see Fig. 12). When asked if they would use a particular solution on a combat mission, the operators seemed to favor the Oakley FR Fast Rope, the HexArmor GGT5, and the Yates Tactical Rappel/Fast Rope gloves, respectively. The first two choices did not have great insulating properties (either objectively or subjectively, but would offer the users quick access to their weapons). Of those gloves that did provide effective insulation, only the Yates Tactical Rappel/Fast Rope gloves were deemed fit for combat.

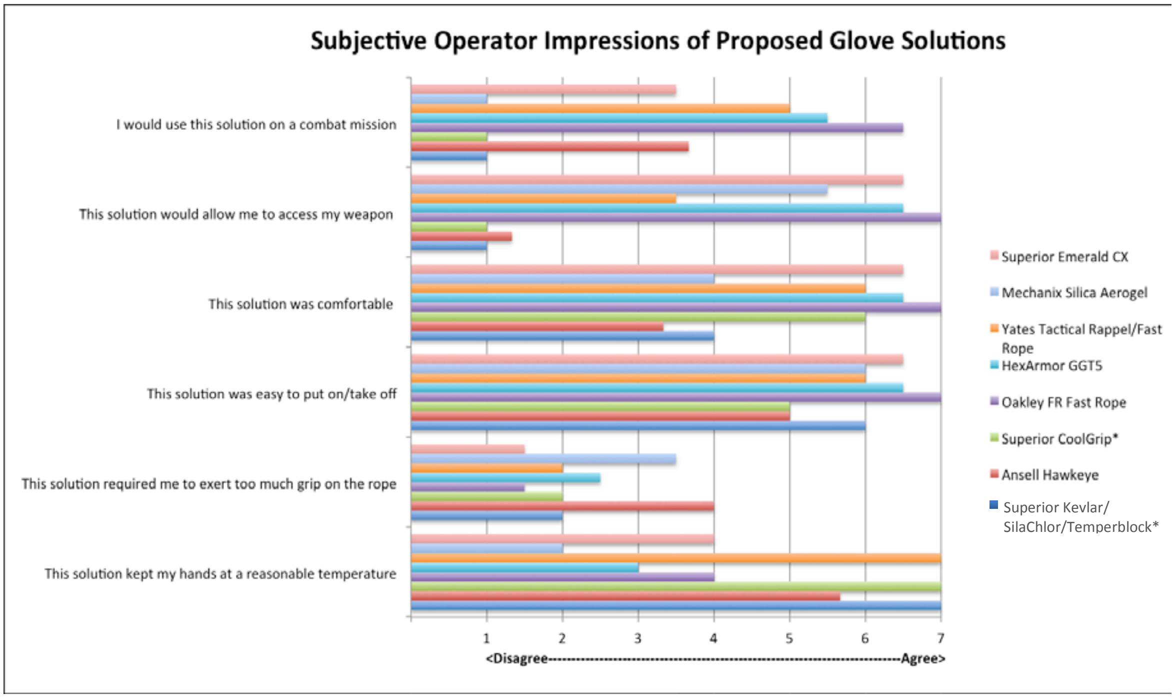


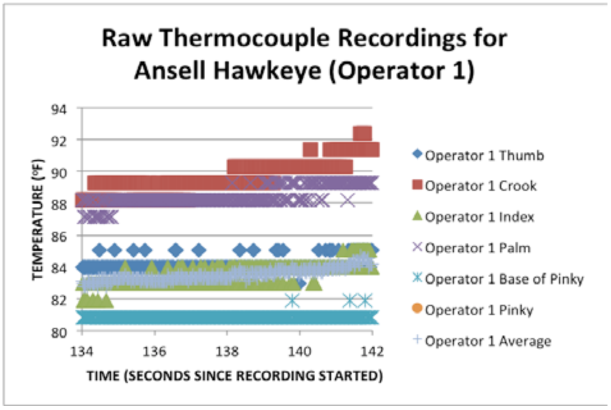
Figure 12. Results for Subjective Feedback Questionnaire (Averaged Across Participants)

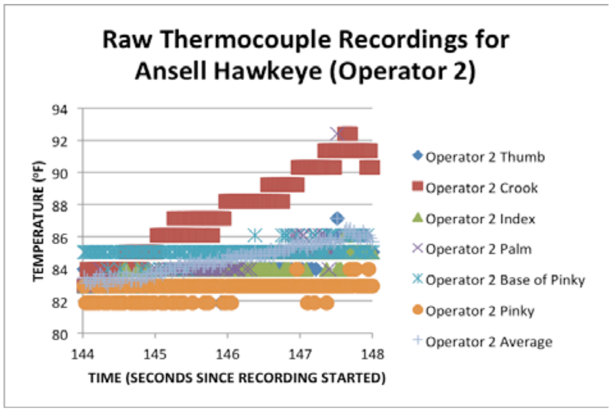
*Results Are Only Available for One Operator

Individual Glove Performance

This section will present some raw results regarding the individual performance of each glove. The first is a photograph of each glove taken after testing to show the wear patterns on the palm after roughly six descents. The next is a set of graphs, which depict the raw temperature scores for each thermocouple position during the course of the Fast Rope descent for each operator (since operators descended the rope at different times after the data logger began recording for each set of gloves, one will see a different 4-second period shown for each operator/glove combination). These graphs will show where the particular hotspots occur for each solution. Finally, a table shows the operators' answers to two open-ended questions on the feedback questionnaire that ask them to list the most positive and negative aspects of each solution (see Figs. 13-20).

Ansell Hawkeye (Current Issue)

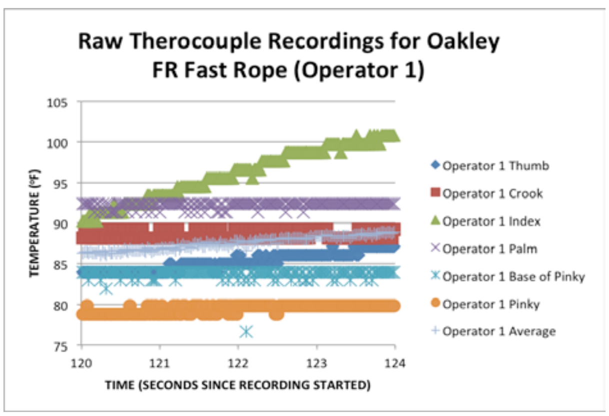


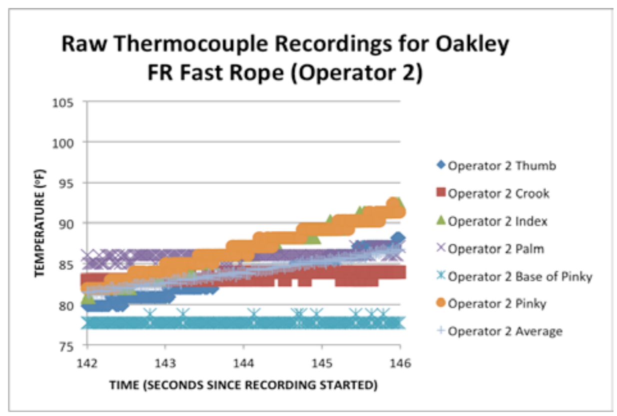


List the most positive aspects of this solution.	Good temperature control. Good grip on the rope.	Inexpensive, fairly effective.	Kept my hands from heating up. Easy to slip on over gloves.
List the most negative aspects of this solution.	Very little dexterity.	Dexterity is not good. It is difficult to manipulate weapon, carabineers, etc.	No dexterity. Couldn't use weapon. Can't manipulate equipment while wearing them.

Figure 13.(Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Ansell Hawkeye

Oakley FR Fast Rope

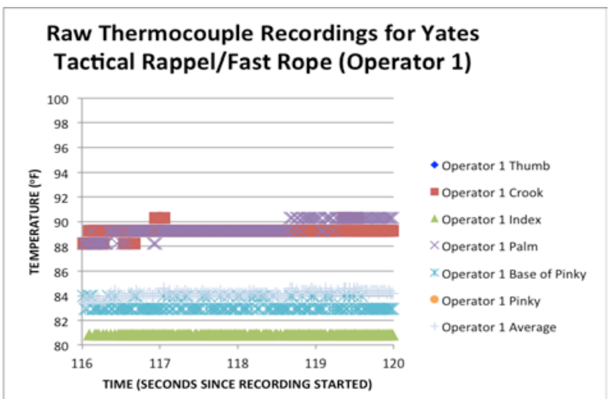


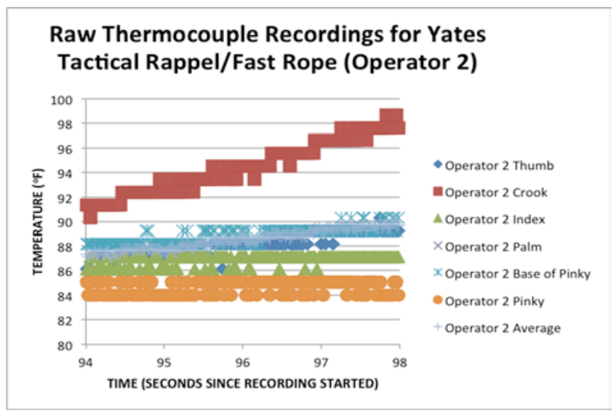


List the most positive aspects of this solution.	Ease of movement, low profile, easy to manipulate equip while wearing them.	Comfortable. Good Dexterity.
List the most negative aspects of this solution.	(2nd operator to test them) you can start to see wear on gloves.	Quick wear on fingers and palm. Hot spot on right hand middle finger.

Figure 14. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Oakley FR Fast Rope

Yates Tactical Rappel/Fast Rope

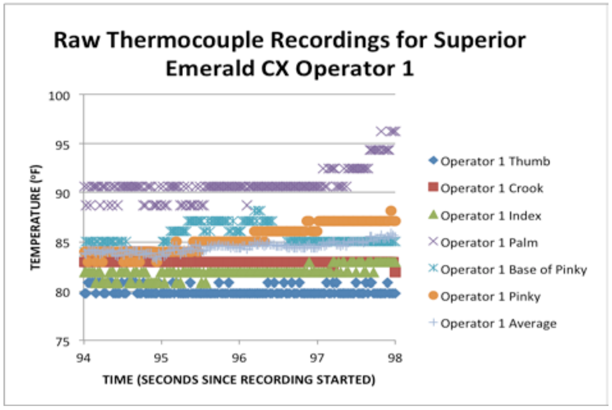


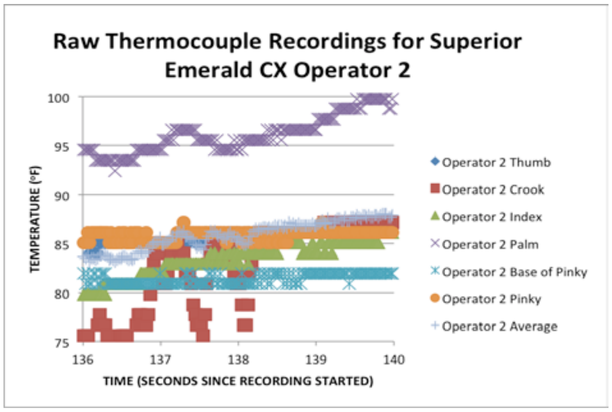


List the most positive aspects of this solution.	Less bulky than heavy leathers. Good for heat dispersion. Durable	Good temperature control. Comfortable.
List the most negative aspects of this solution.	Still too bulky to shoot with. Couldn't manipulate most equip with them - I.E. Radios, some carabineers.	Minimal dexterity. Coverings over the last three fingers cut down on movement.

Figure 15. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Yates Tactical Rappel/Fast Rope

Superior Emerald CX

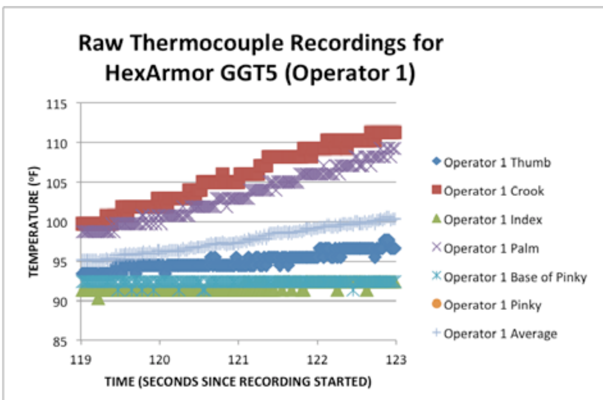


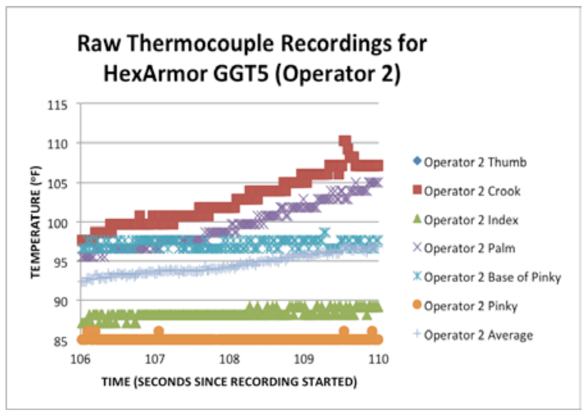


List the most positive aspects of this solution.	Good dexterity. Excellent grip.	Lightweight, easy to put on/take off. Can access equipment + belt loops easily.
List the most negative aspects of this solution.	Rubber on the palm worn out after 5 Fast Ropes. Glove got warmer than leathers but was manageable.	Not durable. Burned through them almost completely after the two 40ft descents.

Figure 16. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Emerald CX

HexArmor GGT5

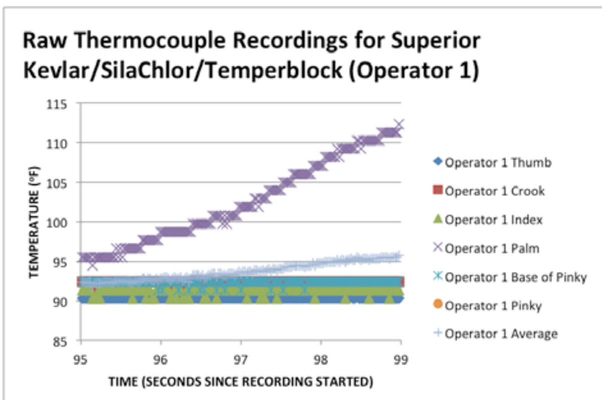


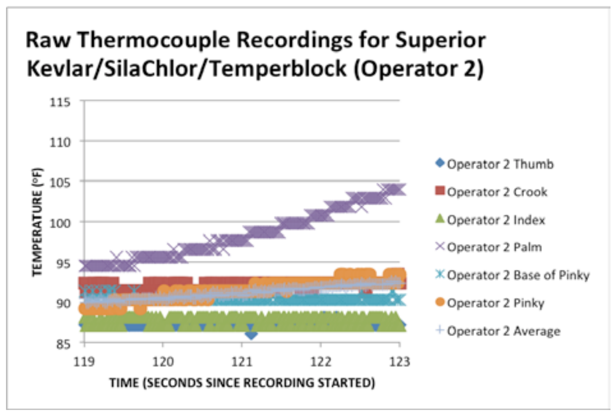


List the most positive aspects of this solution	The glove was comfortable and allowed for good dexterity.	Gloves were good from 20ft, easy to put on and take off. Easy to manipulate equipment. NOTE Question 6 [I would use this solution on a combat mission]: One time
List the most negative aspects of this solution.	Glove had poor temperature control. Glove showed a lot of wear after only a few evolutions.	Got way too hot on 40ft Fast Ropes. Glove actually melted in one spot. Not fit for multiple iterations from any distance over 20ft.

Figure 17. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for HexArmor GGT5

Superior Kevlar/SilaChlor/Temperblock

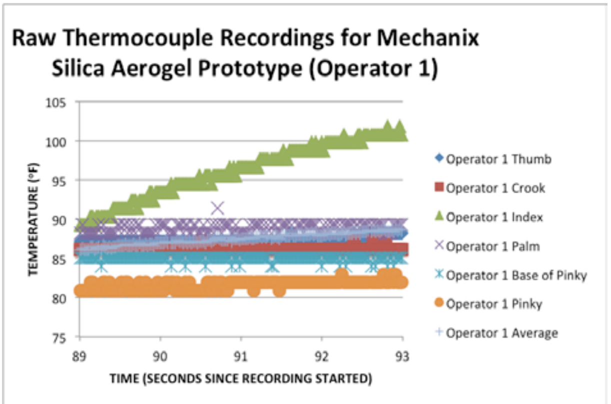


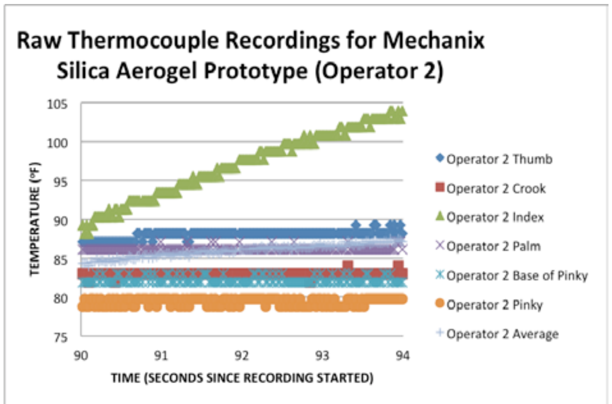


List the most positive aspects of this solution	Best temperature control out of all the test gloves. Easy to slip on and off.
List the most negative aspects of this solution.	Very little dexterity. The rubber on the palm tended to bunch up, tearing it off of the cloth part of the glove

Figure 18. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Superior Kevlar/SilaChlor/Temperblock

Mechanix Silica Aerogel (Prototype)

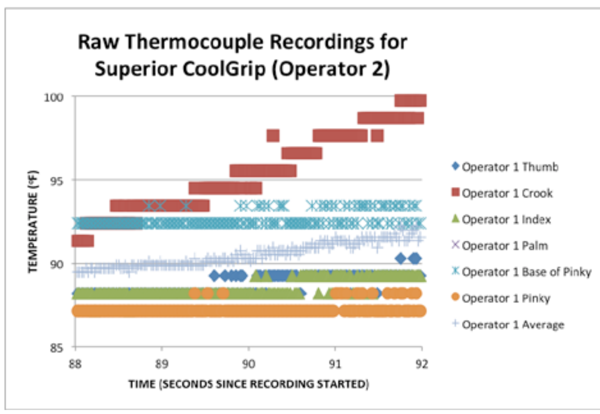




List the most positive aspects of this solution	Easy to put on, good dexterity. Can manipulate equip while wearing.	Good finger dexterity
List the most negative aspects of this solution.	Way too hot on the 40ft Fast Rope. Wouldn't use with full combat equipment above 20ft.	Fingers of gloves got very hot. Pad on palm was bulky and would [not] make gripping a weapon easy.

Figure 19. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Mechanix Silica Aerogel (Prototype)

Superior Cool Grip



List the most positive aspects of this solution	Good temp control. Easy to put on.
List the most negative aspects of this solution.	Loose material bunched up. Unable to manipulate kit/weapon/radio while wearing the gloves.

Figure 20. (Top to Bottom) Photograph of Wear Pattern; Raw Thermocouple Recordings; Open-Ended Operator Feedback for Superior Cool Grip

4.0 Discussion

Thermal Protection

In terms of overall thermal protection, the two-glove solutions, which included the Yates Tactical Rappel/Fast Rope and the Ansell Hawkeye (current issue) heavy leather gloves, outperformed most of the other solutions tested by our team. Only some of the foundry worker's gloves, such as the Superior Cool Grip and the Superior Kevlar/Silachlor/Temperblock gloves were able to achieve the same level of protection with only one layer, but only under certain conditions. However, the tendency for the palms of these gloves to bunch up makes the already strenuous task of gripping the rope even more awkward and although the operators only needed one pair of these gloves to make a Fast Rope descent, they still felt that these solutions were too bulky to use in combat.

For many of these tests, there was a rapid heat rise (steep slope on the data graphs) that occurred in one or two specific parts of the hand. For many of the gloves, these hotspots occurred in the palm or the crook of the hand. But sometimes the highest temperature increases occurred on the fingers. Differences in hotspot positions between operators may be a matter of using right vs. left-handed technique. Differences between gloves can show how their construction affects the way they protect the hand. Ideally, the areas of thermal protection would need to cover all of these areas since operator acceptance could be jeopardized by a single hotspot (e.g. the Mechanix glove had the best protection in the palm but was rejected by the user since the fingers overheated).

The silica aerogel prototype that Mechanix created did show that the material could be incorporated into a glove and that, where applied, would provide an effective layer of insulation for an operator's hands. However, this first-pass prototype would require significant improvements before the warfighter community would use it. The protection must be extended to the fingertips, which experience just as much heat as the palms.

Form Factor

Although thermal protection is important, anecdotal evidence and the results of the operator feedback for this evaluation suggest that there may be some trade space between good insulation and a slim form-factor. The instructors who oversaw the tests reported that the two-glove Ansell Hawkeye solution provides enough insulation for most operators in most situations. Furthermore, a search of the Air Force Safety Database shows that there have been no reported Fast Rope injuries since 2001[11]. Therefore, any potential glove replacements do not necessarily need to have better insulation. Rather, they need to provide at least the same level of thermal protection in a slimmer form factor. This may explain why our two operators would most likely take the Oakley FR Fast Rope gloves with them into combat despite their poor insulation. These gloves have a low profile and are very dexterous. It may be possible to incorporate some of the materials that made the foundry gloves (and the silica aerogel) so effective at insulating the operators' hands into a form factor that is closer to the Oakleys by placing the insulation just where it is needed.

Abrasion Resistance

Even if one could make a pair of gloves that incorporated the sort of materials that would make a one-glove solution possible, it would have to be durable enough to survive multiple Fast Rope descents. Nearly all the gloves tested in this evaluation seem to have short lifespans (the Superior Emerald CX was even tested to the point of failure after 5 descents). The gloves that had a rubbery outermost layer (i.e. Superior Emerald CX, Superior Kevlar/Silachlor/Temperblock) were particularly susceptible to being damaged by abrasion or ablation. As one tries to make the leather in these gloves thinner (either to make the glove itself more low-profile or to allow for the incorporation of insulating layers), the overall solution necessarily becomes less durable because there is less material for the rope to abrade away. Therefore, in order to make a pair of Fast Rope gloves that has the same form factor as tactical gloves, one must also find a way to make them more abrasion resistant (or cheap enough to be disposable). While the HexArmor GGT5 gloves did contain a flexible abrasion-resistant material known as SuperFabric, this particular blend was not capable of withstanding the extraordinarily high heat and abrasion caused by Fast Roping. However, there are other blends of this ceramic-embedded fabric that may be more suited to this application.[12]

What about the Rope?

Though the focus of this evaluation was on the how the end user can better equip himself to deal with friction burns, we would be remiss if we did not also include a discussion of how to make a better Fast Rope. In the last couple of years, the Navy has been working on an innovative Fast Rope design to be used in military combat and other operations. The Radially Compressive Rope Assembly (RaCRA) is designed so that when the operator tightens his grip, the rope compresses and creates an indent so that the uncompressed material below the hand acts as a sort of shelf; the creators refer to this as a "hand holding block"[13]. This helps to lower the amount of friction needed to brake and also allows for varying speeds when descending from helicopters and other vehicles or structures. Just as with a traditional Fast Rope, it allows one to engage/disengage the rope rapidly, so multiple operators can descend in a short period of time, creating a smaller window for the aircraft and the people aboard to be harmed.[14]

However, some questions with such a design would need to be addressed before it could be considered for field use:

- How quickly does a deformed RaCRA recover (i.e. does it behave like memory foam, or will it spring back quickly)?
- How does operator input affect the way he descends (i.e. how hard/quickly does he have to squeeze to stop on the rope, if needed)?
- What is the cost of employing such a system with respect to a traditional Fast Rope?

Once this system has been evaluated in a systematic way, it may prove to be a yet another way of dealing with this problem.

Observations

Based on the data and anecdotal discussions with the operators from the 342 TRS, we have gleaned several parameters to which a new pair of Fast Rope gloves should adhere. Firstly, these gloves <u>must not</u> be thicker than a pair of tactical gloves; they must also contain an insulating layer between the outermost coating and the hand. Good candidates for this layer include: silica aerogel, Silichlor or another flexible, lightweight and non-bulky material that has similar thermal resistivity. If there be a conflict between these two requirements, our feedback sessions with the operators suggest that it is more important for a particular solution to be low-profile, even if it means using a slightly less effective insulator.

Finally, any new solution needs to be rugged enough to protect the insulating layer for multiple descents. Looking at the wear patterns of the gloves that we used for this study, it became apparent that the outer layer must wrap around the fingers and the base of the palm to prevent the unprotected parts of the gloves from abrading away if they slide upwards while the operator descends. One could use heavy-duty, cowhide leather for this layer, but it will likely be too bulky, particularly if it is used in conjunction with a thick insulating layer. Thinner leathers, such as goatskin did not fare well during this test and would likely abrade away after a few descents. It may also be possible to use a ceramic-based outer layer, such as a heavy-grade blend of SuperFabric on areas of the glove that experience the most wear. Using SuperFabric in this way is a double-edged sword. On the one hand, since it is slicker than leather, it will not abrade very easily and it may also produce less friction, and therefore less heat. On the other hand, friction is what allows the operator to brake his descent and if the material is too slick, he may not be able to slow down. Clearly, if this option is explored further, one must perform more tests to make sure the SuperFabric does provide good abrasion resistance without affecting the operator's ability to control his descent.

Recommendations

To investigate what has been learned during this project more fully, we wish to create a new glove prototype that will have elements that should address some of the shortfalls of the gloves evaluated in this test. The glove will be constructed using a sandwich approach. There will be: a base layer on the palm that helps other layers adhere to the glove (the woven nomex blend currently used for tactical gloves should work well here); an insulating layer made of silica aerogel (or a lightweight and flexible insulator with similar thermal resistivity); and a highly-durable outer layer that wraps around the bottoms of the fingers and the palms (with slits for dexterity), made from SuperFabric.

Conclusions

Given how often Special Forces troops use the Fast Rope insertion technique and the criticality of being able to access one's weapon and kit once on the ground, these warfighters need a way to protect their hands from rope burn without compromising their readiness to fight. Although some of the glove materials explored in this report show promise, more work must be done to incorporate them effectively into a low-profile, dexterous form factor. Meanwhile, advances in Fast Rope design and descent devices must be tested more thoroughly to see if they will meet the operational demands of Special Forces missions.

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